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ABSTRACT

This work was performed for the Under Secretary of Defense for Personnel and Readiness, Readiness and Training Directorate, under a task entitled "Development and Assessment of Advanced Distributed Learning (ADL) Prototypes." By reviewing data on classroom and tutorial instruction, this document presents a perspective on the value of technology-based instruction in general and intelligent tutoring systems (ITSs) in particular. It finds the mixed-initiative dialogue and on-demand, real-time generative capabilities to be defining functionalities of ITSs. These functionalities are motivated by basic research into human learning and cognition. From this perspective, development of the ADL initiative and ITSs are viewed as parallel but presently independent activities. This document describes and discusses their common interests in the development and availability of (accessible, interoperable, durable, and reusable) instructional objects on the World Wide Web. These sharable instructional objects can act as either instructional content or algorithmic agents. Sharable instructional objects are likely to reduce the costs and increase the effectiveness of ADL technologies and ITSs. Development of these objects should be cooperatively promoted and pursued by the ADL and ITS communities. Doing so may lead to the development and wide use of personal learning associates, which would allow high quality instruction and decision-aiding to become ubiquitous and affordable. Includes one figure and one table. Provides a glossary of abbreviations. (Contains 41 references.) (Author)

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J. D. Fletcher

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What Do Sharable Instructional Objects Have To Do With Intelligent Tutoring Systems, and Vice Versa?

J. D. Fletcher

PREFACE

This work was performed for the Under Secretary of Defense for Personnel and Readiness, Readiness and Training Directorate, under a task entitled "Development and Assessment of ADL Prototypes."

Despite the many common goals between the development of Advanced Distributed Learning (ADL) sharable instructional objects and intelligent tutoring systems (ITSs), this development is being pursued in parallel but independently. This document is intended to promote more joint effort between these two development communities and show why such joint development will benefit the Department of Defense (DoD) by reducing training and development costs and increasing the effectiveness of its training, education, and decision-aiding activities.

An earlier version of this document was published in the *International Journal of Cognitive Ergonomics* and was reviewed by its editors and two anonymous reviewers.

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EXECUTIVE SUMMARY

The techniques of object-oriented programming are influencing many areas of software development, including the development of tools, materials, and applications for technology-based education and training. Reviews of technology-based instruction across many subject matters and settings have shown that it reduces costs by about a third and also either reduces the time to reach given instructional objectives by about a third or increases the achievement of students by about a third. An important benefit that technology-based instruction provides for military and industrial training is accessibility. It can be used effectively anytime and anywhere.

These capabilities have motivated the Department of Defense (DoD), in cooperation with many other Federal agencies, to undertake an initiative in Advanced Distributed Learning (ADL). ADL combines the economic efficiencies of object-oriented instruction (which provides reusable, sharable instructional objects) and the learning efficiencies and accessibility of technology-based instruction. ADL is also targeting a third set of capabilities, namely those of intelligent tutoring systems (ITSs).

ADL's intention is to allow the real-time assembly, or generation, of instructional objects into instructional or decision-aiding presentations on demand (as needed by individual learners and users). It expects to capitalize on the unique characteristics of ITSs:

- The ability to generate instruction, rather than require developers to foresee and pre-store all possible interactions between users and technology
- The ability to support mixed initiative dialogue, in which either the user or the technology can initiate open-ended discussion.

The ADL initiative and the development of ITSs, then, have several key goals in common:

- Both are generative since they envision the generation of presentations on demand, in real time.
- Both are intended to provide presentations that are tailored in content, sequence, level of difficulty, level of abstraction, style, and so forth to users' intentions, backgrounds, and needs.
- Both have a stake in research intended to accomplish such individualization.

- Both can be used equally well to aid learning or decision-making.
- Both are intended to accommodate mixed initiative dialogue, in which either the technology or the user can initiate or respond to open-ended inquiries or discussion.
- Both will benefit greatly from a supply of sharable instructional objects readily available for the generation of instructional (or decision-aiding) presentations.

Accordingly, ADL is focused on the specification of instructional objects that meet several criteria. Among these criteria, four seem most relevant:

1. **Accessible.** It must be possible to find needed and sharable objects, and they must be *accessible*. Basically, we need widely accepted and standard ways to store objects so that widely accepted and standard ways can be used to find and retrieve them.
2. **Interoperable.** Once found, the objects should be usable. This means that they must be *interoperable* and portable across most—if not all—platforms, operating systems, browsers, and courseware tools.
3. **Durable.** Once implemented, the objects should continue to operate reliably. They should be *durable*. If the underlying platform, operating system, or browser is modified (e.g., when a new version is released and installed), courseware objects should continue to operate as before.
4. **Reusable.** Finally, courseware objects should be *reusable*. Other platforms, operating systems, browsers, and courseware tools should be able to reuse, and perhaps even modify as needed, the original courseware objects.

Specifications intended to meet these criteria are being developed through an evolving series of specifications called the Sharable Content Objects Reference Model (SCORM). Versions of SCORM can be found at the ADL web site (www.adlnet.org).

We expect sharable instructional objects to reduce the costs and increase the effectiveness of ADL technologies and ITSs. Development of these objects should be cooperatively promoted and pursued by the ADL and ITS communities. Doing so will allow high-quality instruction and decision-aiding to become ubiquitous and affordable.

WHAT DO SHARABLE INSTRUCTIONAL OBJECTS HAVE TO DO WITH INTELLIGENT TUTORING SYSTEMS, AND VICE VERSA?

The techniques of object-oriented programming are influencing many areas of software development. Among these areas are the development of tools, materials, and applications for technology-based education and training. This document discusses the value of technology-based instruction in general, intelligent tutoring systems (ITSs) in particular, and how the specification and development of sharable instructional objects can enhance both.

A. WHAT ARE THE CONTRIBUTIONS OF TECHNOLOGY-BASED INSTRUCTION?

Substantial improvements in instructional effectiveness can be obtained by tailoring instruction to the needs and capabilities of individual learners. Studies of one-on-one tutoring provide evidence for these improvements. One widely cited discussion was based on studies performed by Benjamin Bloom. These studies compared the achievement of individually tutored students (one instructor for each student) with that of classroom students (one instructor for every 28–32 students) (Bloom, 1984). It is not surprising to find that individual tutoring in these studies increased the achievement of students. What is surprising is the magnitude of the increase. Bloom reported that the overall difference in achievement across three studies was about two standard deviations, which means, roughly, that tutoring improved the achievement of 50th percentile students to that of 98th percentile students. Two standard deviations is a large difference. Bloom posed it as a challenge to researchers and developers in education.

Why is this 2-Sigma difference (as Bloom called it) a challenge? Why do we not simply provide one-on-one tutoring for all our students? The answer is straightforward and obvious: we cannot afford it. Providing one instructor for each student is, in most cases, prohibitively expensive. Because of this problem, Michael Scriven early on described individualized, tutorial instruction as both an instructional imperative and an economic impossibility (Scriven, 1975).

We may now have the means to break out of this dilemma. Fundamental to the value of our rapidly evolving computer technology is its ability to adjust its actions in real time and on demand to the conditions of the moment. The promise of this capability for instruction has not been lost on researchers and developers. Tutorial instruction and technology-based instruction use this ability to adjust actions responsively to meet the needs of individual students to solve two significant problems: individualized pace and interactivity. These problems confront all classroom teachers and may account for much of the difference in effectiveness between individualized, tutorial instruction and classroom instruction.

1. The Challenges of Classroom Instruction: Pace

The variability in time that different students take to learn and that teachers must accommodate in classrooms can be overwhelming. Despite conscientious efforts to sustain common levels of prior knowledge in classrooms, our current school practices appear to increase these differences by about one year for every year students spend in elementary school (Heuston, 1997). For instance, the average spread of academic achievement in grade three is about 3 years. By grade six, it increases to about 6 years.

Research has helped confirm the extent of this variability. Early on, Suppes (1964) found that the time needed by Kindergarten students to learn to build words from letters varied by about 13:1. Ratios for grade 5 students to master a unit of social studies were found to be 3:1 and 5:1 (Gettinger and White, 1980). In two different studies, the rates of learning observed among hearing-impaired and Native American students were found to be 4:1 (Suppes, Fletcher, and Zanotti, 1975 and 1976). Based on a range of research findings, Carroll (1970) estimated the overall ratio of 5:1 for elementary school students. Even among highly selected students at a major research university, the times needed by undergraduates to learn a programming language have varied by 7:1 (Corbett, 1998, personal communication). The latter result helps confirm earlier observations: even though rates of learning may be determined initially by basic ability, the effects of ability are quickly overtaken by those of prior knowledge and experience with the subject matter (Tobias, 1989).

What happens when we allow students to progress at their own rates, when we individualize the pace of learning as tutors do and as we have long been able to do using technology-based instruction? Some studies have compared the time to achieve specific instructional objectives in classrooms with the time to achieve the same objectives using technology-based instruction. Reviews combining the results of these studies have been reported. Orlansky and String (1979) found that reductions in time to reach instructional

objectives averaged about 54 percent in their review of computer-based instruction (CBI) used in military training. Fletcher (1997) reported an average time reduction of 31 percent in 6 studies of interactive multimedia instruction applied in higher education. Kulik and his colleagues found time reductions of 34 percent in 17 studies of CBI used in higher education and 24 percent in 15 studies of adult education (Kulik, 1994). All these reviews are effectively independent since they reviewed different sets of evaluation studies. On this basis, reductions of about 30 percent in the time students take to reach a variety of given instructional objectives seem to be a reasonable expectation.

The individualization of pace allowed by technology-based instruction, including ITSs, is likely to produce significant savings in time to learn. Do these savings in time matter? Studies have shown that the Department of Defense (DoD) might save hundreds of millions of dollars in specialized skill training if the training time to reach specified thresholds of knowledge and skill can be reduced by 30 percent (National Research Council, 1997). These savings result as much from reductions in training costs as from the value of providing trained personnel ready for duty in operational units earlier.

We might expect such savings to be substantial and operationally significant in military and industrial training, where the organization providing the training pays the students and where the employers and the students have a stake in the rapid mastery of subject matter and the early availability for organizational operations. However, these savings can also be equally valuable in K–12 education. As Gettinger and White (1980) asked, why should we assume that time to learn is unimportant to school children? All societies have a heavy stake in their success. Opportunities, such as those provided by technology-based instruction (i.e., permitting individual students to expand their capabilities and realize their potential as rapidly as possible), may be even more important than they are in military and industrial training.

2. The Challenges of Classroom Instruction: Interactivity

If we consider interactivity to be question-and-answer sequences occurring between students and instructors, could accounting for the differences we observe between one-on-many classroom instruction and one-on-one tutorial instruction also help? Those who study classroom interactions of this sort have found that groups of students ask about 3 questions an hour and that any single student in a class asks about 0.11 questions an hour (Graesser and Person, 1994). By contrast, students in individual tutorial sessions have been found to ask 20–30 questions an hour and have been required to answer 117–146 questions an hour.

Finally, some students taking CBI may answer 8–12 questions a minute. These questions have been selected to meet their individual needs and are immediately graded to provide instant feedback.

The intensity of tutorial instruction provided by technology evidently pays off in student achievement. In a study that compared 97 empirical evaluations made up almost entirely of standard (non-ITS) CBI with conventional classroom approaches, Kulik (1994) reported an effect size advantage for computer-based approaches of about 0.39 standard deviations, or roughly an improvement of 50th percentile students to about the 65th percentile of achievement. In an attempt to determine the advantages to instruction added by multimedia capabilities, Fletcher (1997) summarized a review of 47 comparisons of interactive multimedia instruction with conventional classroom approaches and found an effect-size advantage for these technology-based approaches of about 0.50 standard deviations, or roughly an improvement of 50th percentile students to about the 69th percentile of achievement. Fletcher also reported on 11 ITS evaluations and found an effect size advantage for ITSs of about 0.84 standard deviations, roughly an improvement of 50th percentile students to about the 79th percentile of achievement. In a review of 5 evaluations of the SHERLOCK ITS system, Gott, Kane, and Lesgold (1995) report an overall effect size advantage of about 1.05 standard deviations, roughly an improvement of 50th percentile students to about the 85th percentile of achievement.

We cannot say if we will achieve Bloom's target improvement of two standard deviations, but the available evidence suggests that we are progressing in the right direction through the use of technology-based instruction. These findings also suggest that ITSs raise the ceiling for the effectiveness of technology-based instruction and provide new avenues for improvement over standard classroom instruction. We may be approaching the limits of the improvements we can achieve with general, non-ITS CBI; however, we also have much to learn about the instructional possibilities for ITSs.

3. Are We Getting Anywhere?: Costs

The preceding results show promise for technology-based instruction in general and ITSs in particular. However, if we want to make a difference in the day-to-day practice of instruction, we must address the concerns of those who are making decisions about it. For them, effectiveness is an important consideration but is only one component of the equation. The hallmark of administrative decision-making is the consideration of what must be surrendered to gain some advantage. Generally, these decisions involve tradeoffs between

costs and effectiveness. Decision-making in instruction is no different. We must consider costs and effectiveness.

The ratios of costs for technology-based instruction compared with more conventional instruction can be reported in three categories:

1. The initial investment costs to develop and implement both types of training (technology-based instruction and CBI)
2. The operating and support costs for both types of training once they are in place
3. These two cost categories combined.

In reports structured for this purpose, the smaller the ratio, the better the news for the technology-based training. For one set of studies in which achievement under technology-based training was at least equal and generally superior to that produced by more conventional instruction, Fletcher (1997) reported the ratios to be 0.43 for initial investment, 0.16 for operating and support, and 0.35 overall. In these studies, substituting simulated equipment for the real equipment to be used on the job resulted in most of the cost savings achieved by technology-based instruction. Nonetheless, these ratios suggest that substantial economies can be realized through the use of technology-based instruction and that the return can justify the investment. More complete analyses, based on projections, suggest that the potential savings—not just cost avoidances—for DoD may amount to hundreds of millions of dollars (National Research Council, 1997).

4. In Summary: The Thirds

Assessments of technology-based instruction leave us with "the thirds." Use of technology reduces the cost of instruction by about one-third, and it also either reduces time to reach given instructional objectives by one-third or it increases the achievement of its students by about one-third. The primary payoff for many organizations is, of course, the rapid preparation of personnel to perform operational duties.

B. WHAT ARE THE CONTRIBUTIONS OF ITSs?

It may be best to begin by noting the features that garden-variety CBI can and does provide. Notably it can:

- Accommodate an individual student's rate of progress, allowing as much or as little time that an individual student needs to reach instructional objectives
- Adjust the sequence of instructional content to each student's needs

- Adjust the content itself, ensuring that different students receive different content depending on what they have mastered and what they have yet to learn
- Make the instruction as easy or as difficult as necessary
- Adjust to the learning style (e.g., verbal vs. visual) that is most appropriate for each student.

These capabilities have been available and used in CBI since its inception in the 1950s (e.g., Atkinson and Fletcher, 1972; Suppes and Morningstar, 1972; Fletcher and Rockway, 1986). Those who promote systems with these features by touting them as indicators of newly developed "intelligent" capabilities may be missing some history. Whatever the case, they are using the term "intelligent" in ways that differ from the historical objectives of ITSs—objectives that have been pursued since the late 1960s.

What are these objectives? What is left for ITSs to provide? What can we get from ITSs that is not otherwise available? Two functionalities deserve mention:

1. The ability to allow either the computer or the student to ask open-ended questions and initiate instructional, "mixed-initiative" dialogue as needed or desired
2. Related to the preceding functionality, the ability to generate instructional material and interactions on demand rather than require developers to foresee and pre-store all such materials and interactions needed to meet all possible eventualities.

The first of these functionalities requires the ITS to understand and participate in mixed-initiative interactions with the student. It requires a mutual understanding of a language for information retrieval, decision-aiding, and instruction that is shared by the ITS and the student/user. Natural language has been a frequent choice for this capability, but the language of mathematics, mathematical logic, and electronics have been used, as reported in publications edited by Suppes (1981), Sleeman and Brown (1982), Psotka, Massey, and Mutter (1988), and Farr and Psotka (1992).

Whatever form this dialogue takes, the mixed-initiative dialogue (in which either the student or the instructor can initiate interactions) appears to be a key feature of one-on-one tutorial instruction (e.g., Graesser, Person, and Magliano, 1995). In attempting to secure for our students the benefits of one-on-one tutorials, we may turn to technology-based instruction that specifically seeks to develop and implement mixed-initiative dialogue as an instructional approach. Such a capability has been a goal of intelligent tutoring systems (Carbonell, 1970) for a long time.

The second functionality requires ITSs to devise on demand—not retrieve from storage—interactions and presentations for individual students. This capability involves more than generating elements to fill in blanks in a template. It means generating interactions and presentations from information primitives using an "instructional grammar" that is analogous to the deep-structure grammar of the transformational-generative linguists of a generation ago. This functionality harkens back to the roots of ITS development, as (again) can be seen in the volumes edited by Suppes (1981), Sleeman and Brown (1982), Psotka, Massey, and Mutter (1988), and Farr and Psotka (1992).

Motivations for both these functionalities can be found in basic research into human learning, memory, perception, and cognition. Findings from this research have led us to view all cognitive processes as constructive and regenerative. They have caused general theories of perception and learning to evolve from the fairly strict and logical positivism of behavioral psychology (which emphasized the study of directly observable and directly measurable actions) to a greater consideration of internal, less observable processes that are assumed to mediate and enable human learning and to produce the directly observable behavior that is the subject of behaviorist approaches. The keynote of these newer conceptions of cognition may have been struck by Ulric Neisser who stated, "The central assertion is that seeing, hearing, and remembering are all acts of *construction,* which may make more or less use of stimulus information depending on circumstances." (1967, p. 10).

Neisser was led to this point of view by a large body of empirical evidence showing that many aspects of human behavior, such as seeing and hearing, simply could not be accounted for by external physical cues reaching human perceptors, such as eyes and ears. Additional processes, including an internally, one might say cognitively, generated analysis by synthesis, had to be posited to account for well-established and observable human abilities to detect, identify, and process physical stimuli. Such a process requires an active synthesis of the environment based on a runnable cognitive model, or simulation, that is validated or modified as needed by cues being received from sensory perceptors. It is the actively evolving simulation—not the stimuli alone—that is said to account for what the individual learns.

These ideas were, of course, around long before Neisser published his book, and it is notable that they did not occur only to psychologists. Norbert Weiner, a cybernetician, suggested that, "In both [the living individual and the machine], there exists a special apparatus for collecting information from the outside world at low energy levels and for making it available for the operation of the individual or of the machine. In both cases, these external

messages are not taken *neat*, but through the internal transforming powers of the apparatus, whether it be alive or dead. The information is then turned into a new form available for the further stages of performance" (1954, pp. 26–27; italics are Neissers).

All this leads to the impression that the generative capability sought by ITSs and by Advanced Distributed Learning (ADL) is not something merely nice to have but is essential if we are to advance beyond the constraints of the prescribed branching, programmed learning, and the ad-hoc principles currently used to design technology-based instruction. A generative approach is essential if we are to deal successfully with the immensity, extent, and variability of human cognition.

The key defining characteristic of ITSs and ADL, then, is not the application of computer techniques from artificial intelligence (AI) or knowledge representation or the specification of sharable instructional objects, important as these may be. Rather, it is the functional capability to generate in real time and on demand instructional interactions that are tailored to student requests and/or needs. This generative capability motivated DoD to invest in ITSs originally (Fletcher and Rockway, 1986). At that time, the motivation was to reduce or eliminate the high costs of foreseeing or predicting all possibly needed materials and interactions, programming them, and pre-storing them into CBI. Today, this motivation remains fundamental to those who support ITSs and ADL development.

1. An Example of an ITS at Work

An example of these capabilities can be found in the student-computer, mixed-initiative dialogues supported by the Sophisticated Instructional Environment (SOPHIE), an early and seminal ITS (Brown, Burton, and DeKleer, 1982). SOPHIE used a general-purpose electronic simulator to represent an electronic power supply and create a reactive, tutorial environment for training in electronic troubleshooting. The underlying simulator allowed faults introduced into the system by a (human) instructor or by SOPHIE itself to be propagated throughout the (simulated) power supply in a realistic fashion. SOPHIE employed a semantic network of information about the power supply—one of the most sophisticated natural language understanders ever built into an ITS—and an articulate, expert troubleshooting capability that could not only solve arbitrary faults introduced by students or instructors, but also explain to the student how it solved them.

SOPHIE's reactive environment responded in a realistic fashion to the actions and decisions of a student engaged in practical problem-solving. It employed strategies that shadowed those used by the student to make inferences about the circuit based on the

student's measurements. SOPHIE could thereby determine which deductions the student was using, construct a model of his/her state of knowledge, and use this model to generate explanations in terms that the student was prepared to understand. SOPHIE highlighted the need for intelligent training systems not only to solve arbitrary problems, but to do so in a way that can be explained to students and be understood by them. It pioneered capabilities currently lacking in many information acquisition and retrieval systems.

The following is a student-computer dialogue adapted from SOPHIE:

Student: What is the base emitter voltage of the voltage limiting transistor?

SOPHIE: The base emitter voltage of Q5 is – 0.37 volts.

The first student-SOPHIE interaction in this example is a straightforward question and answer. SOPHIE has introduced a fault into the simulated power supply and the student is trying to locate and repair it.

Student: What about for the current limiting transistor?

SOPHIE: The base emitter voltage of Q8 is .349 volts.

The second student-SOPHIE interaction is a little less straightforward because, in addition to simulating the faulted power supply, SOPHIE must be able to parse the dialogue sufficiently to know that the student is asking for the base emitter voltage of transistor Q8. The meaning of the student's question depends heavily on the context established by his prior question.

Student: What should it be?

SOPHIE: In a working circuit, the base emitter voltage of Q8 is .593 volts.

The third student-SOPHIE interaction continues its dependence on SOPHIE's understanding of context and also requires SOPHIE to extract the answer by simulating both the faulted power supply and one that is operating correctly.

Student: Replace Q8.

SOPHIE: I am going to ask you some questions about how Q8 is faulted. Are any junctions shorted?

The fourth student-SOPHIE interaction indicates a clear step beyond what Brown, Burton, and DeKleer described as a knowledgeable system to what they considered to be an

intelligent system. SOPHIE has progressed from a knowledgeable parsing of its dialogue with the student and simulation of various states of the power supply to a system exercising tutorial intelligence. It shadowed the student's solution path, modeled the student's troubleshooting hypotheses, determined that they are incorrect, elected to capture the dialogue initiative back from the student, and undertook a series of tutorial interactions intended to lead the student to a more correct approach to the problem.

It is difficult to imagine any practical way to achieve this level of instructional functionality without the generative capability and mixed-initiative dialogue that distinguishes ITSs from other forms of CBI.

2. What About Decision-Aiding?

As can be seen, an ITS such as SOPHIE has many elements and capabilities in common with a decision-aiding system, intended in this case to assist an electronics maintenance technician. The differences may lie entirely in the intentions of the user and depend on whether the system is being used to solve a problem or to effect a (more or less) persistent change in the user's knowledge and skills. The underlying computational capabilities appear to be the same.

Is it worth expanding the capabilities of an ITS to support decision-aiding? The U.S. Air Force's development and evaluation of the Integrated Maintenance Information System (IMIS) provided some evidence. Teitelbaum and Orlansky (1996) summarized this evidence. They reviewed and analyzed the performance of technicians who were specially trained to troubleshoot and maintain F-16 avionics systems and compared the performance of these technicians with the performance of less specifically (and much less expensively) trained General Aircraft Technicians.

Table 1 shows the results of this comparison. Notice that the performance of the General Aircraft Technicians became essentially the same as that of the Avionics Specialists once they were trained on the IMIS. Perhaps more notable, however, is that the performance of the General Aircraft Technicians using IMIS was superior to that of Avionics Specialists using the paper-based Technical Orders currently provided as maintenance aids. Finally, it may be worth noting that because IMIS was tied into the inventory and parts databases, it could generate the paperwork needed to order new parts in about a minute for both groups. IMIS provided both sophisticated decision-aiding to the technicians as well as help in completing clerical tasks of a less exotic nature.

Table 1. Results From IMIS Trials

	Correct Solutions		Time To Solve Problems		Time To Order Parts	
	Technical Orders	IMIS	Technical Orders	IMIS	Technical Orders	IMIS
Avionics Specialists	82%	100%	149 min	124 min	19 Min	1 min
General Aircraft Technicians	69%	98%	176 min	124 min	25 Min	1 Min

IMIS supported decision-aiding only for three subsystems of F-16 avionics. Even at that, if its use were expanded to the full fleet of F-16s for these three subsystems, net cost savings to the Air Force would be about $23 million annually. Therefore, using ITS techniques and capabilities to provide instruction and decision-aiding appears to offer substantial benefits.

The emphasis on IMIS as a decision-aiding system, rather than just a maintenance-aiding system, is intended to suggest that this approach is not limited to maintenance or operation of devices. Its capabilities could be applied to more abstract undertakings, such as command and control (C2) in the military and management and administration in the civilian sector.

3. What is the Underlying Technical Idea?

Achieving these instructional and decision-aiding functionalities is an important goal, but it requires a technical idea to make it feasible. Jaime Carbonell (1970) first articulated this idea. He recommended replacing the ad-hoc frame-oriented (AFO) instructional approaches, such as those seen in programmed texts and best described as "intrinsic programming" (Crowder, 1959), with an information-systems-orientated (ISO) approach. The AFO approach of intrinsic programming is widely used in technology-based instruction. It features a presentation (often a paragraph of text and/or a graphic of some sort) followed by questions. A student's answers to these questions lead to different responses, usually different branching paths, by the system. The presentations, the questions, and all possible branching paths must be anticipated and pre-specified by the instruction developers.

Carbonell's ISO approach—or, as we might say today, an approach based on knowledge representation—allowed the instructional system to be generative. As suggested some time ago (Fletcher, 1975), the ISO functionalities possessed by SOPHIE and other ITSs involve computer representation or modeling of the student, the subject matter, and

expert tutoring. This point of view now seems to be commonly accepted and is found to a significant degree in the ITS architectures. Carbonell (1970) and Woolf and Regian (2000), among many others, have emphasized knowledge representation as a key underlying capability for ITSs. Progress is being made. Woolf and Regian emphasize that our ability to represent human cognition has gained considerable potency because of the advances made in cognitive science during the last 10 years. These advances should substantially improve the promise and capabilities of ITSs.

C. WHERE IS THIS TAKING US?

1. The Third Revolution in Learning

The emphasis here on instructional technology brings us to revolutions in instruction. The first of these may have occurred with the development of written language about 7,000 years ago. It allowed the content of advanced ideas and teaching to transcend time and place. The second revolution in instruction began with the technology of books. Books made the content of high-quality instruction again available anywhere and anytime but also inexpensive and accessible to many more people. A third revolution in instruction appears to be accompanying the introduction of computer technology. The capability of this technology for real-time adjustment of instructional content, sequence, scope, difficulty, and style to meet the needs of individuals suggests a third pervasive and significant revolution in instruction. It makes both the content *and* the interactions of high-quality instruction widely and inexpensively accessible—again anytime, anywhere.

2. The ADL Initiative

Building on this possibility, the ADL initiative is now being undertaken in the United States and elsewhere. This initiative is intended to provide education, training, and decision-aiding (or "mentoring") anytime, anywhere. It capitalizes on the growth of electronic commerce and the World Wide Web. It takes advantage of this global—almost irresistible—activity, accelerates it, and applies it to learning. It will help ensure the availability of human competence in many organizations as they face the challenges of the 21st century.

The ADL initiative has been tasked to provide guidelines and specifications for all instructional activities of the United States Federal Government. It is similarly expected to provide guidelines and specifications for the instructional activities of many countries in Europe and in the Pacific Rim. It may succeed because it is not imposing standards developed by the government, but, rather, is pulling together the best ideas, guidelines, and

specifications developed by a variety of industrial, academic, and government sources in the United States and elsewhere. It has become a massive cooperative development that involves economic sectors focused on achieving the ADL initiative's goals, which are to provide learning and decision-aiding capabilities tailored to the needs of individuals anywhere and anytime they are needed.

D. WHAT DOES ADL HAVE TO DO WITH ITSs?

1. ADL and Intelligent Instructional Systems

In the context of ITSs, "intelligent" refers as much to our intentions as our results; however, it is more than a marketing term. It refers to the specific functionalities that are the goals of ITS development. As discussed, these functionalities are distinct from those found in more conventional approaches to CBI. They require ITSs to generate instruction in real time and on demand as required by individual learners. This generative approach is also the goal of the ADL initiative, which is combining the benefits of both object-oriented development and Web delivery with those of technology-based instruction to achieve its objectives.

Despite common goals, the ADL initiative and the development of intelligent instructional systems have been pursued in parallel but separately. The ADL initiative has focused on the specification of sharable instructional objects that can be retrieved from and then delivered over the World Wide Web anywhere, anytime. They can be used and reused to tailor instruction and decision-aiding presentations to the needs of individual learners. They support the core functional capability targeted by the ADL initiative: making the benefits of tutorial instruction and decision-aiding universally and affordably available. The common interests shared by the developers of ITSs and those pursuing the ADL initiative have been noted on both sides.

The ADL initiative is guided by a vision, roughly illustrated in Figure 1, of a future in which everyone has an electronic personal learning associate. This device will assemble learning or decision-aiding presentations on demand and in real time—anytime, anywhere.

The presentations will be exactly tailored to the needs, capabilities, intentions, and learning state of each individual or group (e.g., crew, team, or staff) of individuals. Communication with the personal learning associate will be based on natural language dialogue initiated either by the device or by its users. The device will be small enough to be carried in

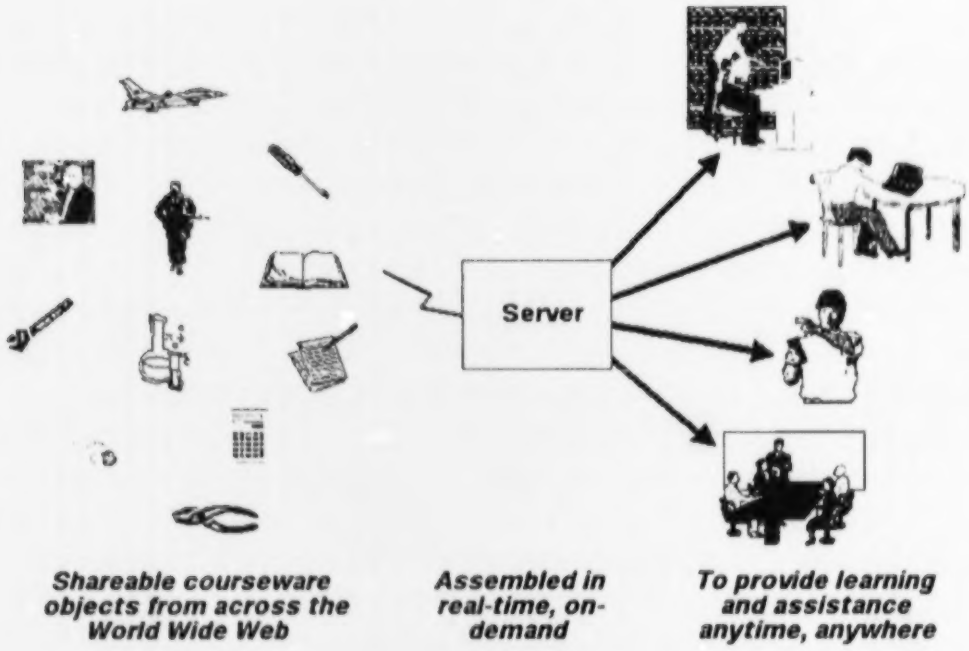
Server
Shareable courseware objects from across the World Wide Web
Assembled in real-time, on-demand
To provide learning and assistance anytime, anywhere

Figure 1. An ADL Future

a shirt pocket, or it will be wearable. It will be used by individuals learning by themselves, in groups, or in classrooms. It will, of course, be wireless.

Most of the technology needed to build such a device exists now. Although we cannot yet fit it into a shirt pocket, advances in electronics should take care of that. What is especially needed for instruction and decision-aiding is content in the form of instructional objects, which we are calling sharable instructional objects. These objects, shown in the cloud on the left side of Figure 1, must be readily accessible across the World Wide Web or whatever form our global information network takes in the future.

Once these objects exist, they must be identified, selected, and assembled in real time and on demand and then handed to the personal learning associates, which provide the instruction or decision-aiding. This work of identifying, selecting, and assembling objects is the job of the server, represented as a box in the middle of Figure 1. By importing "logic" or instructional strategy objects, the server [which today would be called a Learning Management System (LMS)] can acquire the capabilities of the intelligent tutoring/ decision-aiding system we have been discussing. If it does so successfully, it will also

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provide the benefits we have been discussing. However, in the ADL initiative, the underlying processes will rely on sharable instructional objects.

The ADL initiative and the development of ITSs have several key goals in common:

- Both are generative since they envision the generation of presentations on demand, in real time.
- Both are intended to provide presentations tailored in content, sequence, level of difficulty, level of abstraction, style, and so forth to users' intentions, backgrounds, and needs.
- Both have a stake in the research intended to accomplish such individualization.
- Both can be used equally well to aid learning or decision-making.
- Both are intended to accommodate mixed initiative dialogue in which either the technology or the user can initiate or respond to inquiries in natural language.
- Both will benefit greatly from a supply of sharable instructional objects readily available for the generation of instructional (or decision-aiding) presentations.

2. Sharable Instructional Objects

Roschelle and Kaput (1995) emphasized the promise of object-based software, such as that promoted by ADL, for combining many kinds of interactive content in multiple display formats and attaining for education the benefits now being realized in business from the use of integrated office software. Roschelle et al. (1999) illustrated these points by examining the software techniques underlying five object-based education projects that have already been developed. Gibbons and Fairweather (2000) weigh these issues at length in examining the present status and future of CBI.

The cloud on the left side of Figure 1 represents the World Wide Web or whatever we will use in the future to provide our global communication ether. One crucial matter for the implementation of ADL is what has loosely been called "content" in the form of sharable objects represented by the various icons shown in the cloud. People involved in ADL have spent—and continue to spend—much time, effort, and energy discussing these sharable content objects (SCOs). This matter transcends the immediate issues of ADL as evidenced by discussions edited by Wiley (2000) and others.

As presently defined, SCOs could be entire courses, lessons within courses, or modules within lessons. They could be electronic representations of media, text, images, sound, Web pages, or other data that can be presented to students. The size, or "granularity," of SCOs is a matter of considerable discussion. Gibbons, Nelson, and

Richards (2000) emphasized that SCOs will be most useful if they are prepared in sufficiently small chunks that can be accessed and reused by other instructional materials. Access must be rapid and easily accomplished across whatever form our future global information network takes. As suggested by Figure 1, once these SCOs exist, they must be available for assembly in real time and on demand by some sort of servers (middle of Figure 1) and then handed to client personal learning associates (right side of Figure 1).

SCOs could also be material that is not seen by students but is needed to register them for courses, report on their progress, collect them into classes and other administrative groupings, or store data needed to tailor instruction to individual student needs. Significantly, they could also be content in the form of algorithms that aggregate, integrate, and sequence other objects as needed to manage the progress of students toward their attainment of specific instructional outcomes.

Some researchers have provided examples and suggested some architectures for this possibility. Koedinger, Suthers, and Forbus (1999), in their discussion of tutor agents, emphasize their value for "higher-order" reasoning, such as that associated with developing and assessing experimental strategies, determining representation strategies, developing conjectures, drawing conclusions, and making arguments in a science learning space. Ritter and Koedinger (1996) suggest a general architecture that translates the mouse clicks, key presses, and other responses of students into semantic descriptions that can be used for tutoring and managing student progress toward curriculum goals.

These activities are the kinds of functions that LMSs are now expected to perform. These LMSs are intended to be generalized capabilities for many different types of students, subject matters, curriculum structures, instructional approaches, and curriculum objectives. However, there seems to be a clear tradeoff between the amount of functionality that can be built into these LMSs and their generality. The more functionality built into them, the less general purpose they become. LMSs that import these functionalities as objects are likely to be more flexible, powerful, and generalizable.

In this sense, the current discussion of "content" and what SCOs might be echoes the controversy that occurred early in the development of digital computers: whether data (traditional content) and logic (algorithms) should be stored in different ways and in different locations of the early machines (Goldstine, 1972). John von Neumann settled that discussion. He recommended storing data and logic together as digital bits in a common memory. The nature of SCOs, their disposition, and whether to apply a solution analogous to von Neumann's remain to be determined.

Still, SCOs have become the foundation for ADL. The availability of SCOs will significantly reduce the costs of preparing instruction, decision-aiding, and job-performance assistance for technology-based delivery. This is likely to be true whether the SCOs are assembled in advance by course authors and developers or, as suggested by Figure 1, are assembled on demand and in real time by server algorithms incorporated in or imported into LMSs. For these reasons, ADL development is presently focused on packaging SCOs in anticipation of what is called by Spohrer, Sumner, and Shum (1998), among others, the "educational object economy." The primary idea behind such an economy is that the emphasis in preparing materials for technology-based instruction (or decision-aiding) will shift from the current concern of preparing content components, or instructional objects, to one of integrating already available content into meaningful and relevant presentations.

ADL developers recognize that this software engineering concern is only a beginning. The primary goal of ADL is not to promote tinkering with software objects, but to develop the functional capability of producing instructional outcomes anytime, anywhere they are needed or desired. The ADL initiative has made substantial progress at this software engineering level, but it must also address real learning issues. It must determine how to assemble instructional objects to achieve targeted instructional objectives.

These two areas of software engineering and instructional design are not independent. They must coordinated and "harmonized" to achieve the ADL vision. This point suggests that designers and developers need some understanding of the underlying ADL architecture and its software specifications to ensure that ADL presentations bring about efficient and effective learning. It also suggests that the software engineers designing SCOs must (along with their meta-data packaging and assumptions concerning course structures, LMS structures, and communication protocols) understand and accommodate all varieties of instructional approaches and what each requires for software support.

This vision, which foresees the development of an instructional object economy, must start with the specification of sharable instructional objects. Fortunately, many individuals (technicians, software engineers, instruction designers, cognitive researchers, and so forth) from organizations representing all sectors of the economy (government, industry, and academic) in the United States and elsewhere in Europe and Asia have joined in this quest. Development of these objects has become a global effort. Those involved in the U.S. ADL initiative mostly need to orchestrate the effort and document its results.

Sharable instructional objects that support ADL functional requirements must meet some criteria. Among these criteria, four seem most prominent:

1. **Accessible.** It must be possible to find needed and sharable objects, and they must be *accessible*. Basically, we need widely accepted and standard ways to store objects so that widely accepted and standard ways can be used to find and retrieve them.

2. **Interoperable.** Once found, the objects should be usable. This means that they must be *interoperable* and portable across most—if not all—platforms, operating systems, browsers, and courseware tools.

3. **Durable.** The objects should be *durable*. Once implemented, the objects should continue to operate reliably. If the underlying platform, operating system, or browser is modified (e.g., when a new version is released and installed), courseware objects should continue to operate as before.

4. **Reusable.** Finally, courseware objects should be *reusable*. Other platforms, operating systems, browsers, and courseware tools should be able to reuse, and perhaps even modify as needed, the original courseware objects.

Specifications intended to meet these criteria are being developed through an evolving series of specifications called the Sharable Content Objects Reference Model (SCORM). Versions of SCORM can be found at the ADL website (www.adlnet.org).

Specifying these objects arises from the intersection of disciplines concerned with learning and cognition, information storage and retrieval, and software engineering. Packaging the objects so that they are accessible will depend on the model of cognition and learning or the learning strategy trying to find them. This packaging requires the development of a taxonomy that is sufficiently robust to accommodate many models and strategies. Aside from such models of human cognition, learning, and instruction, some representation of the physical world is also required to accommodate comprehensive range of objects. Finally, interoperability and reusability require techniques of software engineering that are compatible with the prevailing global ether—which today is the World Wide Web—and with the many operating environments in which the instructional objects will be used. Given the difficulty of the undertaking, it is fortunate that it has become a global quest. Current progress toward these ends can be viewed through many portals. The ADL website is a good a place to start.

E. SUMMARY

This discussion suggests that:

- Substantial improvements in instructional effectiveness can be obtained by tailoring instruction to the needs and capabilities of individual learners. Evidence for these improvements can be found in studies of one-on-one tutoring.

However, in most applications, providing one instructor for each student is prohibitively expensive.

- Using technology can make the benefits of individualized instruction affordable. Evaluations of CBI in general and ITSs in particular provide evidence of these benefits.
- Combined with the availability of sharable instructional objects available from the Web, ITSs will lead to the development and wide use of personal learning associates, which will allow high-quality instruction and decision-aiding to become ubiquitous and affordable.
- This is a desirable result.

If Kurzweil's (1999) projections are correct, computers may become more effective in providing instruction than human tutors even if humans use all the techniques Graesser and his colleagues found they now neglect (Graesser, Person, and Magliano, 1995). We may not be implanting integrated circuits in our brains as Kurzweil suggests, but the goal of using technology to discover more than any human agent can about the unique potential of every individual and devising effective and individualized procedures to reach it seems an appealing and realistic prospect.

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14. ABSTRACT

By reviewing data on classroom and tutorial instruction, this document presents a perspective on the value of technology-based instruction in general and intelligent tutoring systems (ITSs) in particular. It finds the mixed-initiative dialogue and on-demand, real-time generative capabilities to be defining functionalities of ITSs. These functionalities are motivated by basic research into human learning and cognition. From this perspective, development of the Advanced Distributed Learning (ADL) initiative and ITSs are viewed as parallel but presently independent activities. This document describes and discusses their common interests in the development and availability of (accessible, interoperable, durable, and reusable) instructional objects on the World Wide Web. These sharable instructional objects can act as either instructional content or algorithmic agents. Sharable instructional objects are likely to reduce the costs and increase the effectiveness of ADL technologies and ITSs. Development of these objects should be cooperatively promoted and pursued by the ADL and ITS communities. Doing so may lead to the development and wide use of personal learning associates, which would allow high-quality instruction and decision-aiding to become ubiquitous and affordable.

15. SUBJECT TERMS

computer-based instruction (CBI), education, intelligent computer-assisted instruction (ICAI), intelligent tutoring systems (ITSs), object-oriented programming, sharable instructional objects, technology-based instruction, training

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GLOSSARY

ADL	Advanced Distributed Learning
AFB	Air Force Base
AFO	ad-hoc frame-oriented
AI	artificial intelligence
AL	Armstrong Laboratory
C2	command and control
CAI	computer-assisted instruction
CBI	computer-based instruction
DoD	Department of Defense
IDA	Institute for Defense Analyses
IMIS	Integrated Maintenance Information System
ISO	information-systems-orientated
ITS	intelligent tutoring system
LMS	Learning Management System
SCORM	Sharable Content Objects Reference Model

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